

Visualization tool for increased quality of vision

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Abstract

Considerable resources are currently spent on making society more accessible to disabled people. A large group that is often missing is people with moderate vision loss caused by normal ageing and disease. These people may very well meet the visual requirements for driving license but can still experience great difficulty in daily life. For example, symptoms may arise in environments with low levels of contrast in combination with bright light sources, a situation often caused by inappropriate design. This causes glare and is a rising problem due to the development of new light sources.

The new lighting systems have much higher light levels and distribute the light in new geometries and colours that can be troublesome for large groups of people. The urge of saving energy, and the fast transition into unproven lighting systems, may have consequences in terms of reduced quality of lighting.

To demonstrate these problems our research group is working with computer software that simulates various visual degradations by filtering digital images from cameras or CAD models. To test the tool we have designed indoor test environments. Observers with impaired vision due to normal ageing have assessed the lighting situations by performing normal actions and contrast tests. We have compared the real experience in the light situation with the simulated and predicted outcome from the software.

In this presentation we will demonstrate problematic lighting situations and present visualizations using our tool. As the reason for bad design often is lack of understanding and knowledge from decision makers and planners, we aim at contributing with a tool that can improve quality assurance that takes visual aspects into account.

Keywords

Glare, contrast sensitivity, hdr, lighting, ageing, vision, cataract, perception

Introduction

The ageing eye

In normal young eyes, the optical media is clear. As we grow older the eyes optical media starts to absorb and scatter light. This scattered light causes a luminance superimposed on the retinal image, which reduces the contrast levels. This effect is called veiling luminance (Fry 1953) and is notable for most people, for example when obscuring a glaring light source temporarily with our hand. With increased light scatter, the contrast sensitivity threshold of the visual system finally sets a limit. This age-related change, which starts around the age of 40, is chiefly caused by an opacification of the lens and becomes more pronounced as we grow older. The magnitude of the scattering increases by at least 2-3 times throughout life (Allen 1967). Slowly, the visual system has greater and greater problems with detecting low contrast objects and the problem with glare becomes pronounced.

Light scattering is the main cause of disturbances of vision seen in ageing people, such as increased glare sensitivity, decreased contrast sensitivity, and reduction of visual acuity (Ben-Sira 1980). When light sources are introduced in the visual field a veil of light is formed as a consequence of the light scattering. The strength of the light veil is proportional to the intensity of the light source and declines away from the light source in the visual field. If the veil is strong enough to cause a reduction in visual performance we have experienced the phenomena of disability glare. Another common age-related problem is the reduced ability to adapt to changing lighting levels (Gunkel & Gouras, 1963). This impairment can also be described as glare but must not be mixed up with the definition of disability glare.

A disease like cataract (clouding in the lens) is also a result of the normal ageing process. Even though cataract surgery is the most common surgical procedure it is still the leading cause of blindness worldwide (WHO 2005). The clouding process progress slowly and many persons are suffering from visual problems long before they are diagnosed and listed for surgery. More than 17% of the Americans older than 40 years have cataracts and the number of persons who have cataract will rise by about 50% by 2020 (NIH-EDPRSG 2004). At the age of +75 year almost 50% have had cataracts.

With age, the eye lens transmits less light due to increased light absorption. Also, the pupil diameter is reduced (senile miosis) resulting in less light transmitted to the retinal image. These two factors combined results in significantly more light needed for older adults. To compensate for the light reduction in the eye the lighting levels has to be increased. This can be of great challenge since adding more light sources, or increasing the power, can result in cumbersome disability glare. The ability to navigate, and the sense of security, are something that is very much influenced by the lighting quality.

Visualizing glare problems

Today there are no tools to ensure that lighting meets the requirements for people with visual impairments and therefore the lighting designer needs to rely only on his own experience of light. A lighting designer might claim that a luminaire is glare-free, or that there is enough light, but lacks the ability to see with the eyes of others. Even an experienced light planner can have difficulties to realize how much disability glare there is in a scene. Every light source has to be taken into account; even diffuse reflections and daylight can give a significant contribution. Calculations of the impact from each source within the visual field are a laborious work and is often left out or simplified.

Attempts to solve this problem have been made by producing visualizations. Some studies have implemented models for light scattering to estimate image contrast and problems with glare using standard low dynamic range digital images (Hogervorst 2006, deWitt 2006). In the real world intensity variation are much richer than standard digital images can represent. To get a correct result, high dynamic range data is needed to capture the huge variation, for example between a spotlight and a critical part of a scene that is darker.

The main objective of our research is to develop computer software that visualizes how people with impaired vision, due to normal ageing, actually “see”. The aim of the study presented here, is to test if it is possible to visualize problematic lighting situations correctly. A specific aim is to perform a pilot test in a real environment to verify how our visualizations agree with impressions from observers. In addition, we measure contrast levels in the simulated images to find problem areas in the same scenes that the observers were asked to perform contrast sensitivity tests in.

The developed software, called VISSLA (VISualization and Simulation of Light scattering and Aberrations), can transform high dynamic range images or CAD models of visual scenes, into an impression like they were seen through another person’s eyes.

First, a retinal image is calculated that consists of photometric correct light distribution allowing absolute contrast measurements for visibility threshold analysis. Second, the visualization of the visual impression from the retinal image is calculated which is an attempt to create an illusion of an apparent brightness from light, (Spencer 1995, Yoshida 2008). The problem is that the human eye has the advantage of constantly changing the adaptation when looking at different parts of a scene. A digital image on a computer screen or paper will instead have an average brightness that might both under, or overestimate the contrast in an image. A computer screen is also limited to two orders of magnitude of luminance while the human visual system is able to handle more than three orders of magnitude (Hood and Finkelstein 1986).

The next two sections will describe two methods that we use to evaluate the quality of the test scenarios. Method A refers to computer analysis with VISSLA and Method B refers to evaluation of the visual performance of observers with impaired vision in the test room.

Method A: Visualization tool and image analysis

The software tool VISSLA was developed as a tool to quickly perform a glare analysis of a scene. Up to this date, year 2012, no such tool exists and light planners are referred to make cumbersome hand calculations using glare index equations.

VISSLA simulates how an image is formed on the retina and visualizes what that retinal image will “look like” for someone. The simulation of the image formation on the retina takes both optical refraction errors (aberrations) and intraocular light scattering into account.

High Dynamic Range Imaging

The input to VISSLA has to include the full intensity range of the scene that will be analysed. It must also have enough number of intensity steps for a meaningful analysis. For this purpose we use High Dynamic Range (HDR) photography technique where several photos of a scene are taken with different exposure settings. HDR photography is described in depth for example by Reinhard, (2006). The input image can also be generated in a CAD software if the light distribution on all surfaces in the scene is calculated adequately, which seems to be possible today with global illumination algorithms (Pharr and Humphreys 2010).

The transformation of a HDR image into a low dynamic range representation (8 bit range) that can be shown on a computer screen is called tone mapping. The basic operation is that light levels over a certain level are truncated and represented as “white” in the image and the other light levels are compressed using a logarithmic function to mimic the nonlinear sensitivity of the retina. There are many variations on this theme (Devlin 2002) and also many attempts on local adaptation have been made, for example the Retinex adaptive filter (Maylan and Süssstrunk 2006) but all suffer from different limitations. Our approach will be described below.

For HDR photography we use a Nikon D300 DSLR camera and the shutter speed is increased four times between each exposure. ISO and aperture settings are constant and images are saved in a 14 bit RAW format. We then merge the images into one HDR image using an algorithm that preserves intensity linearity. All processing is done in MATLAB (www.mathworks.com) except for the conversion from Nikon RAW format, where we use the open source program “dcrw”. (www.cybercom.net/~dcoffin/).

The HDR image calculation is calibrated against a spectrophotometer (Model PR-650, Photo Research Inc.) to assure correct luminance levels. The HDR images can then be used for further image processing, inspection of contrast levels or for absolute luminance measurements in VISSLA software tool.

To view the HDR image on a computer monitor we currently use a simple tone map algorithm. It has two parameters: the white point level (W_p) and Gamma correction (γ) according to eq (1).

$$L_{out} = L_{in}^{\gamma} \quad \text{for } L_{in} < W_p \quad \text{and} \quad L_{out} = W_p \quad \text{for } L_{in} \geq W_p \quad (1)$$

Where L_{in} is the luminance of the HDR image and L_{out} is the luminance of the tone mapped image. In all simulations $\gamma=0.4$ and W_p was chosen so that the image brightness resembled the scene. The red, green and blue channels of the image are processed individually.

Simulations

The image formation in the human eye is simulated by filtering the HDR image i.e. convolution of the image by a point spread function (PSF). The software can handle most optical imperfections but in this study we limit the eye model to include light scattering only.

Empirical models of the human eye have been constructed from glare measurements over many years. International Commission on Illumination (CIE) has adopted standards for the glare of a normal observer, expressed as a PSF valid in an angular domain $0^\circ - 100^\circ$. It is referred to as the “total glare function”, (Vos and van den Berg, 1999). The standard glare function is valid for a healthy eye and describes the light scatter due to normal ageing. However, there are large individual differences also in normal ageing.

When an eye scatters more light than normal and is approaching the diagnosis of cataract, the veiling luminance is more pronounced and the PSFs have to be modified accordingly (de Waard, IJspeert, van den Berg and de Jong, 1992). However, in this pilot study we use a PSF proposed by Beckman (1992) that is given by eq. (2), which has the advantage of separating the contribution from scattered and refracted light.

$$\text{PSF} = A e^{-\left(\frac{\theta}{\theta_0}\right)^2} + B \delta \quad (2)$$

where θ is an angle, θ_0 is the width at half maximum, δ is Kronecker delta function and A and B are constants determining the amount of scattered light and refracted light respectively. In the software the amount of total light scattering is set by a ratio between the two contributions.

Image analysis

The basic analysis method in VISSLA is to compare the original HDR image of the scene with a simulated retinal image. Absolute luminance values (cd/m^2) can be read from the image and contrast levels can be calculated along cross sections in the image. By switching between original and simulated image it is easy to quantitatively measure how much the contrast of an object is reduced due to imperfections of the eye. Note that in this stage all analysis is done from the HDR data and no subject interpretation is needed.

The tone mapping, or visualization of a visual impression, might on the other hand need some adjustments before a proper low dynamic range image can be presented. Like a printer needs to be calibrated for correct match between print out and computer screen, the parameters for the tone map algorithm needs to be adjusted for good match between a visual impression from a display and the real scene. We have found that a good way is to first optimize the tone mapped *original* image to best match the real scene when displayed on the device at hand. Brightness levels and colour saturation are judged and adjusted accordingly. Next, the visualization of the visual impairments can begin.

Depending on the situation and purpose of the study, different approaches can be chosen. Sometimes the PSF parameters, or degree of scattered light, is adjusted so that a specific person find the best match between what he actually sees and the visualization on the display. This is possible due to the fact that a displayed image will not cause glare, as the luminance levels are much lower than in the real scene.

Another scenario is that we want to visualize a specific visual problem, like the effect of bad lighting for elderly people or problems with insufficient contrast of obstacles in public areas etc. Then the purpose with the visualization is mainly to highlight problem areas so that the design can be improved. Neither the exact degree of visual impairment, nor the exact light conditions are fully known, but a simulation can show the effects of a worst-case scenario.

Method B: Evaluation in test environment

Observers with impaired vision due to normal ageing participated in our pilot study. The observers were first examined in an examination room to grade their visual status before they entered the test environment. During the tests the observers assessed the lighting situation in the room. The testing was ended by comparing their description of the room with our computer visualizations of different amount of light scattering. The computer simulations methods, equipment, testing room, observers and testing procedures are reported below.

Design of the test room

The project has focussed on different entrance situations and communication areas, since they are crucial for orientation and glare problems are common. The test environment presented in this pilot study was an experimental room built as a hallway without windows (Fig. 1). The hallway is small, however spacious enough for allowing the use of a wheelchair. It has three doors, a mirror, two pictures, a coat-hanger, a chair and a shelf. Three walls are painted almost white, the fourth as a patterned wallpaper. The front door has a strong blue colour and the other two doors are white. The door cases are middle grey.

The visual performance was tested when the observer was sitting in the chair in the lower right corner of the room (Fig. 1). Contrast sensitivity test charts were presented at position P1 and P2, at about 2.8 m distance.

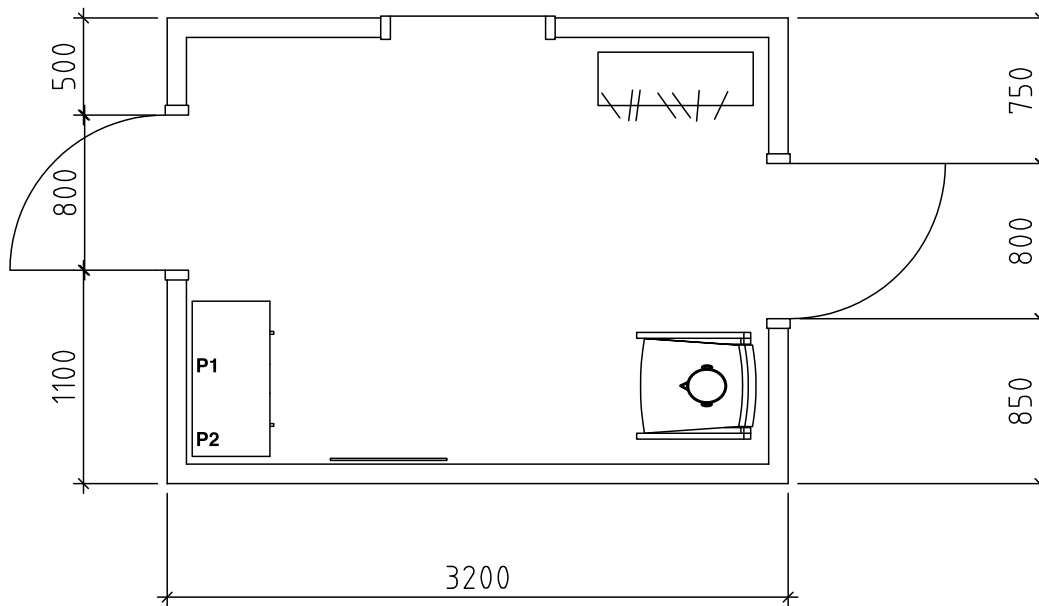


Figure 1. Plan of the hallway. The visual performance was tested when the observer was sitting in the chair in the lower right corner of the room. Contrast sensitivity test charts were presented at position P1 and P2, at about 2.8 m distance.

Light settings

We used three different ceiling light fixtures, two wall light fixtures and four spotlights to create different light settings. In the pilot study presented here, we tested four specific settings:

Light setting 1 (Fig. 2) represented a fairly common lighting situation with expected glare problems. The ceiling light fixture, made of opaque glass, was equipped with three halogen bulbs. The wall lamp placed beside the mirror had an opaque screen of glass, not covering the downward facing light source. It was equipped with a low energy bulb with matte glass.

Light setting 2a (Fig. 3) had a textile light fixture with three halogen bulbs in the ceiling and the wall light fixture from setting 1. This setting was an intermediate step where we switched ceiling light fixtures, while keeping the wall fixture.

Light setting 2b represented a similar lighting situation designed to avoid glare (Fig. 4). It had a textile light fixture in the ceiling and a wall light fixture with a plastic screen covering the light source. It was equipped with a halogen bulb.

Light setting 2c complemented with spotlights (Fig. 5). The halogen spotlights were placed in two different corners of the room. This setting was designed to increase the light level, which was expected to be too low in the other settings.



Figure 2. Light setting 1.



Figure 3. Light setting 2a.



Figure 4. Light setting 2b.



Figure 5. Light setting 2c.

Observers

The observers were selected by convenient sampling. The criterion was that they should have normal vision for their age, or diagnosed cataract. The age span was between 59 and 98 years old. They were all cognitively well and were asked to terminate in case they found the study too tiring. These kinds of studies do not require any application for ethical evaluation, since personal data were not asked for and there were no aim to physically or psychologically affect the observers. In this pilot study there were six observers, three men and three women. One of the observers had one eye with diagnosed cataract and one with normal ageing, which made her a particularly valuable observer. She volunteered for several sessions.

Testing of observers visual status

Measurements on visual acuity (VA) and contrast sensitivity (CS) were performed with both eyes (binocularly). The test persons wore their prescription glasses, if needed. All measurements were performed using FrACT, the 'Freiburg Visual Acuity and Contrast Test'. It is free computer software for automated, self-paced measurement of the visual acuity (Bach 1996) and contrast sensitivity. A 'Landolt-C' optotype was used as test symbol. The symbol consists of an annulus with a gap in one of four directions and a total of 30 symbols were presented during each test. The test persons had to give an answer regardless if the test symbol was seen or not ('Forced-choice' method). A 15" Apple eMac computer was used during the test and an operator pushed one of the 4 arrow-keys on the keyboard according to the test person's response. After each test the 'FrACT'

software presents the VA or the CS depending on the choice of test method. In the VA-tests the 'Landolt-C' symbols were presented with decreasing size, and during the CS-tests the contrast of a fixed size symbol was decreasing until the individual contrast threshold was found. All of these tests were performed at a distance of 3 meters, except for one observer (discussed in section Results and analysis). Contrast levels were calculated according to the Weber contrast definition (Thaung, Beckman, Abrahamsson and Sjöstrand, 1995). During contrast testing the test symbol size was equal to a decimal visual acuity of 0.1.

As a third test, the contrast sensitivity was measured ones again but now under exposure of glare sources in the observers' field of view (CSglare). Four glare sources were positioned one degree outside of each possible location of the Landolt-C symbol (Fig. 6). The glare was induced by a Fostec DCR® II Halogen light source with randomized optical fibre bundle. The bundle is split into four identical fibre branches with equal light intensity distribution – one for each glare position. The test person was told to avoid looking direct at the glare sources during testing to minimize the effect of after-images. The luminance of the computer screen was about 100 cd/m² and each glare source was set to about 1000 times higher in luminance.

The results from the contrast sensitivity measurements were calculated as glare factors, $GF = CS / CS_{glare}$. The glare factor shows how many times higher the contrast of the test symbol must be in order to be correctly identified when the glare source is introduced in the field of view.

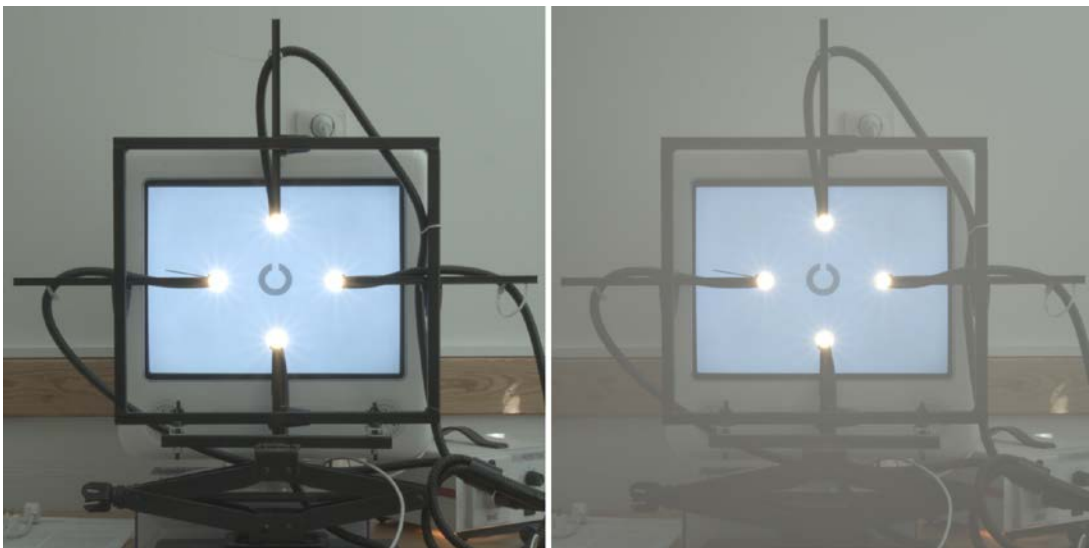


Figure 6. Photos of glare test equipment with a Landolt-C ring shown on screen and four optical fibers emitting light. The picture to the right is simulated in VISSLA and indicates how the glare sources generate a veiling luminance in the scene, causing reduced contrasts.

Test symbol charts

To test the observers visual performance in the room we used printed test charts (Landolt-C symbols) with two different sizes, gap size 2mm (small) and 8mm (large), see figure 7. The two sizes correspond to a decimal visual acuity of about 0.4 and 0.1, at the test distance of 2.8 meters. Twelve charts with different contrast levels were printed on a large format ink printer (HP-800PS) on white paper. The charts were also protected using matt laminating sheets. The contrast levels were calculated to follow a logarithmic scale but due to a printer error only nine charts were used in the study. Consequently, the remaining steps did not follow the desired logarithmic gradation.

The nine charts had contrast levels in the following steps: 2, 4, 10, 11, 13, 20, 26, 37, and 55 %. The contrast levels were calculated from measurements by a spectrophotometer (PR-650, Photo Research Inc.). The contrast levels are expressed as per cent grey level where 100% means black symbol on white background. The better visual performance an observer has, the lower contrast can be detected. Thus, the performance improves as the per cent values decrease.

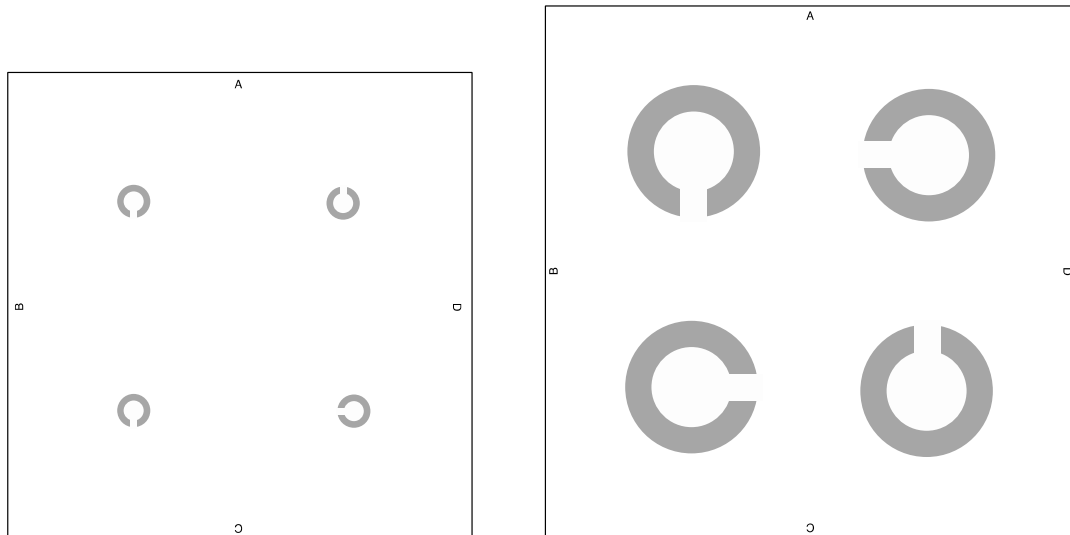


Figure 7. Illustration of contrast sensitivity test charts used in the study. Left chart is referred to as small and right chart is large.

Procedure in experimental room

The research approach was structured interviews with various tasks and tests. Each observer was allocated 1.5-2 hours for a session, including vision tests. Two of the observers made more than one session. Different assessment techniques were used in order to achieve understanding of how the observers perceived the different lighting situations. Standardised tests of visual acuity, contrast sensitivity and colour deficiency were performed prior to the assessment in the experimental rooms (see details under section “Testing of observers visual status”).

In the experimental room the following assessment techniques were used:

- *Spontaneous comments.* During the initial 5 minutes adaptation time the observers were encouraged to give spontaneous comments on the room as a whole.
- *Visual evaluation of light* (Billger et al 2004 & Stahre & Billger 2006) They were then asked to describe various aspects of the light, such as light distribution in the room, light level, shadows, perceived colour of light, dimness and clarity. In addition they were asked if they perceived glare.
- *Contrast sensitivity tests.* A ‘Landolt-C’ optotype was used as test symbol. The symbol consists of an annulus with a gap in one of four directions. Charts with symbols were placed in crucial parts of the room.

- *Visual comparisons of the room.* Comparison between the real room and VISSLA images. The simulated images were presented on a digital display system (Apple iPad 3rd generation 2012).

In light setting 2c an additional evaluation method was used:

- *Preference of light level.* The observer was invited to adjust each light fixture to achieve best possible light situation for this hallway. As criteria the situation should be comfortable and provide best possible condition to choose cloths, to see properly in the mirror and to see the face of a visitor (the experimental leader) inside the door.

Photometric measurements of the different light situations in the rooms were made.

Results and analysis

Computer vision test

The result of computer vision tests (FrACT) for all observers is shown in Table 1.

Table 1. List of observers and results from visual acuity test and glare factor test.

Observer	Age	Visual acuity			Glare Factor			Comments
		L	R	B	L	R	B	
A	F 75	0.5	0.7	1.0	4.2	1.8	3.9	Cataract in left eye.
B	M 98			0.3			5.1	Cataract in both eyes
C	M 74			0.6			2.2[‡]	Cataract in both eyes
D	M 76			1.0			1.6	Normal ageing
E	F 59			1.4			3.1	Normal
F	F 74			1.0			1.9	Normal ageing

[‡] For observer C the glare test had to be carried out at a too close distance which resulted in a too low Glare Factor due to wrong angle to the glare sources. Also the light power was lowered too much in an attempt to compensate for the short distance.

Contrast sensitivity charts

The result from contrast threshold measurements in the test room for all observers is shown in Table 2. Test symbols are described in section “Test symbol charts”, above. A crossed cell means that the particular setting was not tested, a cell marked with “-“ means that none of the symbols in the series were detected and a cell marked with “all” means that all symbols could be detected.

Most observers could see all large symbols and the limit was reached on the small symbol charts. Observer C found a limit on both the series of large and small symbols, in scenario 1 and 2b.

It is interesting to note that observer B who had the worst visual acuity and the highest glare score among the observers, found a great improvement in scenario 2c where the light conditions could be adjusted freely. When light levels were raised to maximum power (about 1500 lux), observer B improved the detection from 13% to 4% contrast level on the large symbol charts, and could detect the 26% contrast level small symbol chart!

Table 2. List of results from contrast threshold measurements, using Landolt C test symbols with gap size 2 mm (small) and 8 mm (large). Binocular testing at a distance of 2.8 meters.

Observer	Scenario 1		Scenario 2a		Scenario 2b		Scenario 2c		Comments
	small	large	small	large	small	large	small	large	
A	-	10%	X	X	10%	all	10%*	X	*Max light power
B	-	20%	-	11%	-	13%	26%*	4%*	*Max light power
C	37%	4%	X	X	37%	10%	X	X	
D	4%	all	X	X	X	X	4%*	all	*Max light power
E	10%	all	10%	all	10%	all	X	X	
F	10%	all	X	X	10%	all	X	X	

Observer D, E and F did not find any significant improvement between the different scenarios as they had reasonably good visual acuity and glare score.

Observer "A" was asked to do the test with one eye blindfolded. "A" was diagnosed cataract on the left eye and we examined how that influenced the performance. Results are listed in Table 3.

Table 3. List of results from contrast measurement test for observer A with one eye blindfolded.

Test results for participant A										
Symbol Size	Scenario 1			Scenario 2b			Scenario 2c			Comments
	L	R	Bi	L	R	Bi	L	R	Bi	
Large	20%			11%	10%		10%*			*150 and 177 lux
Large			10%	10%		4%	10*			*200, 340 and 570 lux
Large							4%*			*1000 and 1550 lux
Small			26%			11%				

Observer A found a great improvement in scenario 2c even at low illumination levels on the wall (150 to 177 lux) and the detection limit raised from 20% to 10%. At 1000 lux illumination, the detection was improved even more to 4%!

Visual perception of the light settings

The difference between the light settings was primarily the choice of wall luminaire. The one used in setting 1 and 2a, *i.e.* the frosted glass screen and visible light source, caused, as expected, the strongest effect of glare. Even the glass luminaire in the ceiling used in setting 1 could cause glare, especially when the observers stood up. All but one of the observers complained about glare problems in this setting. Except for glare, the light in the room was assessed as fairly acceptable; some found it too dark while others stated that it was lit enough. As expected, the notion of an adequate light level differed among the observers. This constituted for example the ability to find ones shoes, see ones face in the mirror or read a book. For one of the observers an adequate light level constituted the minimum requirement of sufficient light, *i.e.* not waste unnecessary energy. Other comments described light setting 1 as fragmented and intrusive.

Light setting 2b was described as a softer light situation than setting 1. It was pointed out to be less worrying, comfortable and relaxing. One observer stated that the two scenarios were quite similar, however in scenario 1 you could not look directly at the luminaries, which was possible in 2b. Two of the observers had divergent comments on 2b. One of these two observers found the room to be unnecessarily illuminated. The other, on the other hand, said he did not experience

glare in scenario 1 and he found 2b to be worse lit when evaluating the contrast charts. The illumination measured under the ceiling luminaire, at 140 cm above ground, was the same (177 lux); however the light distribution differed in the two settings, especially in the area around the mirror.

The addition of spotlights in light setting 2c gave a more even, higher light level in the room. The room was perceived nicer as and more vivid than the other light settings. One observer with cataract stated that the colours became more vibrant.

Light setting 2b was described warmer as and more yellowish than setting 1, which all of the observers perceived as whiter. In setting 1 two of the observers pointed out that the perceived light was matte, diffuse and that the colour of light was slightly yellowish, while two others described it as greyish white.

Comparisons between the real settings and the simulations

Light scattering simulations were calculated using VISSLA. Examples of simulation series of light setting 1 and 2b are shown in figure 8 and 9. The scattered light appears as a cloud around the bright light sources. The proportion scattered light is given in per cent and refers to how much light that is distributed away from an ideal image.



Figure 8. Light setting 1 with simulation of increased light scattering; 0%, 20%, 40% and 60%, respectively.



Figure 9. Light setting 2b with simulation of increased light scattering; 0%, 20%, 40% and 60%, respectively.

For the observers with cataract on both eyes it proved not possible to compare the real settings with the simulated photos, since their blurry vision only increased the blurriness of the photos. However, observer A with cataract on only one eye made sessions using both eyes, the normally aged eye and the cataract eye. Observer A was an observant person with normal colour vision. Visual acuity with both eyes was good, with one eye at a time it was worse. With this in mind, it was valuable to listen to A's comparisons between image and room. Another observer who was sensitive to glare, however without diagnosed cataract, was very observant and made comments on the images which were also helpful. We can also compare the descriptions of these two observers with normal vision and with observers who were not sensitive to glare.

Generally, the comparisons indicated that the simulated images lacked contrast. The gradients of shadowing and illuminated patches in the real room did not show in a sufficient way in the images. The door cases were more distinct in reality, and the images lacked colour saturation. Observer B perceived the room as darker than the normal sighted younger members of the project group.

Observer A's comparisons indicated that: the colour saturation decreased with increased scattering. VISSLA simulated A's level of scattering as too blurry over a too large area (see fig 10). This complied with the results from the contrast sensitivity test made in the room; there were no distinct difference between the glaring setting 1 and the non-glaring setting 2b.



Figure 10. Light setting 1 with low and moderate light scattering. One observer stated that the left figure agreed with overall perception of the room, but the highlighted area in the right figure illustrated how she perceived the local area affected by the glare.

The results of the testing of the observers visual status made it possible to rank the observers expected performance.

Contrast measurements in HDR images

We have also measured contrast levels in the HDR images of the test scenarios that can be compared with the contrast threshold levels found from the contrast sensitivity tests. Figure 11 shows a photo of a test chart with large symbols to the right of the wall fixture. Image to the left is original photo and image to the right shows a simulation of 40% light scattering. Contrast measurements in the HDR image on the test chart shows that the contrasts are reduced from 11% to 3% in the right image.



Figure 11. Light setting 1 with simulated light scattering; 0% in left picture and 40 % in right picture. Contrast measurement in the HDR image on the test symbol chart, shows that the contrast drops from 11% to 3% in presence of light scattering.

We conclude that if the eye suffers from 40% light scattering, simulations show that only a quarter of the contrast reserve is left on the retinal image. That means about 2-3% contrast, which is close to the detection limit, according to contrast sensitivity curve under these illumination levels.

Therefore it seems reasonable that the contrast sensitivity threshold is about 10% in this situation, which agrees with result for observer A in scenario 1 and 2b in Table 3.

Concluding Discussion

We have developed the tool VISSLA that captures the light levels in a scene, and calculates the image that is formed on the retina of the human eye, taking into account the optical imperfections of the eye. Thus the eye model does not claim to be a complete interpretation of human vision as it only covers the *optical* limitations of vision. In this study we also limit the eye model to only include the effects of scattered light in the eye, phenomena that is related to ageing effects of the human eye. Scattered light adds a veiling luminance on the retinal image that will reduce contrasts and maybe hide objects in the scene. The study was focused on lighting design and the effect of various luminaires in a scene, and under such circumstances scattered light is the main cause of reduced visual performance.

The light distribution that falls on the retina is the foundation for our perception of a scene. Information that is lost up to this stage will hardly be recovered, no matter how intelligent the human brain can perform any image processing! In VISSLA we can either analyse the calculated retinal image with regard to light levels, intensity contrasts and colours or we can visualize how the retinal image is perceived.

The analysis of the retinal image is a question of reading intensity levels and making a judgment if objects are visible or not based on visual thresholds. The visualization however, includes conversion of the image so that it matches the adaptation level of the retina. In this process information will be lost because of the limited dynamic range and intensity resolution of the eye. The crucial problem is that we also have to take into account the performance of the display device that will be used for viewing the image. The human eye has many times greater dynamic range than any computer screen that exists today, so the tone mapping algorithm also has to shrink the intensity levels to fit this even lower performance.

We found that it is not meaningful to present a tone mapped image of strong light sources and dark areas in the same image, because the limitations of the resulting tone mapped image will be too confusing for the observers, so that they cannot make a realistic judgment of the correctness. Thus we conclude that the visualized images need to be cropped to a narrow field of view with a moderate dynamic range that can be handled with the tone map algorithms without distorting contrast or colours in the image.

All observers using both eyes found the visualization with no light scattering to be the best match even though some were diagnosed cataract. It was only possible for the one observer, who had one normal-sighted eye and one cataract eye to judge which level of simulated light scatter that was the best match as she could reason around the difference between the two eyes and compare with the images. She found the simulated image with 20% light scattering to be best match.

In the hallway study, a major problem was to test enough parameters. It was time consuming and demanded long sessions with elderly observers. The main outcome from the pilot study presented here, was methodological results and indications for further studies. One improvement will be to wallpaper the room with contrast test symbols and coloured patterns, to expose the most affected parts of the room.

One problem, when studying rooms with different lighting situations is the sequential comparisons. However, sequentially is necessary, because we need to study the hallway from within and be adapted to the illumination. In this study, we had the opportunity for a comparison of the different light settings with photos, simulating the predicted perception of different grades of cataract.

We conclude that longer interviews with few observers are more valuable for this kind of investigation than to include a big number of observers.

With this project we hope to contribute to an increased knowledge on the concept of glare among lighting designers. A common misunderstanding about glare is that it almost exclusively refers to adaptation and not on light scattering in the lens. To raise awareness about glare problems is an important step in inclusive design.

Summary

Considerable resources are currently spent on making society more accessible to disabled people. A large group that is often missing is people with moderate vision loss caused by normal ageing and disease. These people may very well meet the visual requirements for driving license but can still experience great difficulty in daily life. For example, symptoms may arise in environments with low levels of contrast in combination with bright light sources, a situation that often caused by inappropriate design.

This causes glare and is a rising problem due to the development of new light sources. The new lighting systems have much higher light levels and distribute the light in new geometries and colours that can be troublesome for large groups of people. The urge of saving energy, and the fast transition into unproven lighting systems, may have consequences in terms of reduced quality of lighting.

Knowledge about visual limitations in human eyes will result in improved indoor and outdoor lighting design, better planning of senior people homes, and lighting in public spaces, with minimal risk of glare and improved visibility. It seems that the new trend using small high luminance light sources is not based on knowledge of the visual limitation of the human eye. Another problem is that young people with perfect eyesight do not always realize the visual degradation with age and visual impairment, e.g. cataract. A third problem is that the slow process of visual degradation is seldom obvious to an ageing person, until it is too late.

To demonstrate these problems our research group is working with computer software that simulates various visual degradations by filtering digital images from cameras or CAD models. To test the tool we have designed indoor test environments. Observers with impaired vision due to normal ageing have assessed the lighting situations by performing normal actions and contrast tests. We have compared the real experience in the light situation with the simulated and predicted outcome from the software.

In this presentation we will demonstrate problematic lighting situations and present visualizations using our tool. As the reason for bad design often is lack of understanding and knowledge from decision makers and planners, we aim at contributing with a tool that can improve quality assurance that takes visual aspects into account.

Our visualization tool hide all complex algorithms and make knowledge from vision research available to a broad field of professionals working with lighting design, traffic safety, health and geriatric care. Using this tool they can avoid costly mistakes and design better environments for the whole population and elderly people in particular.

With this project we hope to contribute to an increased knowledge on the concept of glare among lighting designers. A common misunderstanding about glare is that it almost exclusively refers to adaptation and not on light scattering in the lens. To raise awareness about glare problems is an important step in inclusive design.

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